



FINAL TECHNICAL REPORT FOR:  
"Physiology of Selective Attention"  
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We have made progress in five related areas - practice effects, intertrial effects, whether attention acts as a spotlight, whether a master boundary map exists in the brain, and the nature of dual-task interference.

### Practice Effects

We performed a pair of matched studies, on practice and repetition effects in speeded choice tasks, so that the relation of practice to repetition could be determined (Pashler and Baylis, 1991a,b). In the paper dealing with practice, we reported a series of five experiments. In the first experiment, subjects performed 750 trials of a speeded choice task mapping different categories of symbols (e.g., letters, digits) onto different responses. We found excellent transfer to new items in the trained categories (Exp. 1). However, when arbitrary sets of stimuli were mapped onto each response, subjects were much slower when new stimuli were introduced (Exp. 2), even when the size of the potential stimulus set was held constant (Exp. 3). To our surprise, responses to already-trained items were as slow as responses to new items. In our fourth experiment we used a mapping of categories to responses, and found that shuffling the assignment of stimuli to responses drastically slowed responses. However, changing to a spatially homologous mapping with responses on the other hand produced excellent transfer (Exp. 5).

Together, these results indicate that practice in speeded choice tasks affects primarily the response selection stage, rather than perceptual processing or motor responses. Practice seems to work primarily by strengthening links between category representations and spatially defined responses.

Furthermore, when an arbitrary collection of symbols are mapped onto a

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given response, practice produces an *ad hoc* category representation, and strengthens links between individual items and the category, as well as links between the category and the response.

In a study of the effects of practice on a simple line orientation task (Pashler and Shiu, 1992), we found that improvements of performance are specific to the visual quadrant in which practice has taken place. The improvement with practice does not require that the subject receive feedback about their accuracy of performance, but does require that subjects are performing an orientation discrimination task, rather than simply being exposed to the stimuli.

We investigated the brain basis of acquisition of a three-choice discrimination (Baylis, Moore and Pashler, 1992a). In this study monkeys with lesions to the medial temporal lobe, including the hippocampus and overlying cortex, were compared to normal monkeys in their ability to learn a three choice discrimination. We found that lesioned monkeys were unimpaired in making non-selective responses and unimpaired in detection of stimuli. However, when required to make spatially selective responses on the basis of the stimuli, monkeys with temporal lobe lesions were severely impaired, and rendered generally unable to learn the task. In a further study of the effects of medial temporal lobe lesions on response selection (Baylis, Moore and Pashler, 1992b) we showed that these lesions lead to rapid forgetting of the mappings between stimuli and responses by the lesioned monkeys. As a result, the lesioned monkeys were unable to acquire an arbitrary mapping of non-spatial stimuli onto spatially selective responses, even with extensive training.

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### Intertrial Effects

Our set of studies examining intertrial repetition effects (Pashler & Baylis, 1991b) used the same types of tasks as in the study of practice. The first five experiments demonstrated that the repetition effect is quite stimulus specific: a succession of different stimuli that call for the same response produced little repetition benefit, unless the stimuli differed only in very superficial ways (e.g., in color). These results would be consistent with a perceptual locus for the repetition effect, but Experiment 6 showed that if the response mapping changes from trial to trial, the advantage for stimulus repetitions was abolished. The results indicated that locus of the repetition effect is at the stage of response selection. However, the stimulus-specificity of the effects indicated that immediate repetitions produce or strengthen transient links that "short-cut" the response selection stage. By contrast, the results in the preceding paper indicate that practice primarily strengthens response selection at the categorical level, rather than shortcutting it. One implication of all these results, then, is that the practice effect is not created simply by the decay and accumulation of the traces responsible for repetition effects.

We also investigated how errors affect performance on subsequent trials. As predicted by Rabbitt, people gradually speed up until an error is made, after which the next trial is very slow and accurate. Such an effect was seen in normal monkeys but not in those with medial temporal lobe lesions. In fact, no improvement in performance following errors was ever seen in these monkeys, suggesting that many of their learning impairments may be due to an inability to modulate behavior based on whether errors are made. We investigated whether normal and lesioned monkeys showed normal speed-accuracy tradeoff, that is whether accuracy was improved at longer reaction times. Probably as a result of their inability to modulate accuracy, the

monkeys with lesions to the medial temporal lobe showed almost flat speed-accuracy tradeoff functions, whereas normal monkeys showed the same pattern as people.

We also studied error correction in people (Baylis and McLeod, MS In Prep) and showed that the response latency to make an error was unrelated to the response latency to a subsequent error correction response. This supports an independent accumulators model of choice response. In such a model evidence for different responses - in this case the error response and the correct response is accumulated independently. This is in contrast to a random walk model according to which a new search for a correct response must be initiated in response to an error. However, no independent accumulator models of choice response can satisfactorily explain why incorrect responses following correct responses are so rare. We are developing a model in which evidence accumulates and meets two thresholds - one for response and a second for prevention of any further responses. When evidence accumulates for correct responses it rapidly passes both thresholds, preventing further (erroneous) responses. However, when evidence accumulates for incorrect responses it passes through the second threshold at a later time, allowing for error corrections to be elicited.

### **The Spotlight Metaphor for Visual Attention**

We have amassed considerable evidence to suggest that a spatial spotlight is not an adequate metaphor for the operation of visual attention. First, using a paradigm based on that of Eriksen and Eriksen (Perception and Psychophysics 1974) we have shown that factors other than proximity, such as common motion (Driver and Baylis, 1989), common color (Baylis and Driver 1992) and

good continuation (Baylis and Driver 1992) can constrain whether distractors cause interference or not. The spotlight view would predict that only proximity could affect interference. We also attempted to relate the Eriksen distance effect to the Treisman feature integration theory in a study in which looked at the distance effect of distractors which were discriminable from targets by a single feature versus those which were discriminable by a conjunction of features (Driver and Baylis, 1991). We found that a distance effect was only seen in the case of distractors defined by a single feature, and not when distractors were discriminable from targets only by a conjunction of features. This is contrary to the prediction from Treisman's feature integration theory that individual features should be "free floating" and hence not readily localizable.

In Rapid Sequential Visual Presentation Tasks (Cave and Pashler MS In Prep) we studied the ability of subjects to name the highest of a large set of digits presented. We showed that moving the target unpredictably to different locations does not affect subjects' ability to perform this task. However, further work shows that location may be special in that it mediates selection , even when the criterion of selection is color. Evidence for this comes from tasks requiring exclusion of half the digits based on their color.

### **Combining Dimensions for Object Recognition**

The visual system recognizes objects whose boundaries and contours are defined by differences in various dimensions, including color, luminance, texture and relative motion. Our work helped to characterize this process both functionally and physiologically. Pashler (1988) found evidence that texture and color boundaries are detected separately. For instance, when subjects had

to detect a unique element (singleton) differing from the background in texture (orientation), random variation in the color of the background elements had no effect. Similarly, when subjects had to detect an element unique in color, random variation in the orientation of background elements did not retard performance.

In more recent work, we have attempted to understand how boundaries detected in different "feature maps" are joined up to allow object recognition to occur. One possibility is that boundaries recognized separately in different dimensions can separately access long term memory for shape recognition. The alternative is that the boundaries detected in different dimensions are merged into a "master boundary map" prior to shape recognition. Several experiments (Pashler & Witte, 1992) favored the latter possibility. Subjects were required to recognize two objects, one defined by differences in color, the other by differences in texture. Sometimes the two objects were adjacent, and sometimes they overlapped. If shape recognition could operate separately for the two sets of boundaries, then performance in the overlapping condition should have been at least as good as that in the adjacent condition. In fact, however, performance was severely degraded in the overlapping condition, as the Master Boundary Map hypothesis would predict.

In other experiments, we found subjects were required to recognize two adjacent objects, both depicted by differences in color between the elements in the figure, and the elements in the background. We manipulated the relationship between the particular features used to define the figure and the background in the two adjacent displays. Performance proved to be impaired when the feature that defined the figure in one display also defined the background in the other display, and vice-versa. (E.g., relatively poor performance when one figure was defined by red elements against a green

background, while the other figure was defined by green elements against a red background). This result is inconsistent with the hypothesis that object recognition is based purely on a feed-forward flow of information into the master boundary map, with object recognition depending purely on the boundaries detected in the preceding stage. Instead, the results suggest that figure-ground segregation (usually considered to be a purely pre-attentive process) in fact relies at least partially on a feedback process where regions containing features of attended objects are accentuated with respect to other regions. In that way, when the features defining figure and ground in one object are reversed in the other object, a degree of bistability results, with consequent impairment in performance.

We studied whether there is neurophysiological evidence for a single "master map" of object boundaries, examining specifically whether such a map could exist in inferotemporal cortex (Baylis, Mueller and Pashler, 1993). We studied the responses of single cells in inferotemporal cortex to the visual presentation of patterns defined either by gray-scale or texture differences. The patterns were two-dimensional Walsh functions either in black and white or in one of three pairs of textures. One texture pair was chosen since it showed rapid segmentation, one showed moderately good segmentation and one showed poor segmentation requiring considerable attentional effort. It was found that many cells discriminated between members of sets of patterns defined in each of these ways. However, only the rapidly segmenting texture patterns lead to a similar pattern of responses to those of the black and white set. Thus, while neurons in inferotemporal cortex code the differences between the different texture patterns, no single representation of each pattern was present, suggesting that this part of the brain does not contain a single "master boundary map".

### **Dual Task Interference**

Another series of experiments addresses one of the most basic questions regarding the functioning of visual selective attention. We asked whether visual attention requires the same central mechanism as that required for selecting overt motor responses. Pashler (1992) required subjects to perform two tasks: a speeded manual response to a tone and an unspeeded report of a cued target letter in a brief masked array. Stimulus onset asynchrony (SOA) between tone and array was varied. If the attention shift to the target was delayed by the first task, then there should have been more second task errors at short SOAs and on trials with slow first-task responses. In fact, SOA effects and dependencies were minimal. Results were unchanged in further experiments in which the relation between cue and target was symbolic, spatially "unnatural" or based on the color of the target. The conclusion is that the fundamental cause of dual-task interference (the response-selection bottleneck) is attributable to a mechanism that does not control visual selective attention.



**Full Length Publications**

- 1) Baylis, G. C. and Driver, J. (1992) Visual Parsing and response competition: the effect of grouping factors. *Perception and Psychophysics* (In Press).
- 2) Baylis, G.C., Driver, J., and McLeod, P. (1992) Movement and proximity constrain miscombinations of color and form. *Perception* (In Press)
- 3) Beech, A., Agar, K., and Baylis, G.C. (1990) Reversing priming while maintaining interference. *Bulletin of the Psychonomic Society* 27, 553-555.
- 4) Driver, J. and Baylis, G.C. (1989) Grouping by motion in selective attention: The spotlight metaphor breaks down. *Journal of Experimental Psychology: Human Perception and Performance* 15, 448-456.
- 5) Driver, J. and Baylis, G.C. (1991) Target-distractor separation and feature integration in visual attention to letters. *Acta Psychologica* 76, 101-119.
- 6) Pashler, H. (1992). Shifting visual attention and selecting motor responses: Distinct attentional mechanisms. *Journal of Experimental Psychology: Human Perception and Performance*.
- 7) Pashler, H. E. and Baylis, G. C. (1991a) Procedural learning 1: Locus of practice effects in speeded choice tasks. *Journal of Experimental Psychology: Learning, Memory and Cognition* 17, 20-32.
- 8) Pashler, H. E. and Baylis, G. C. (1991b) Procedural learning 2: Locus of intertrial repetition effects in speeded choice tasks. *Journal of Experimental Psychology: Learning, Memory and Cognition* 17, 33-48.
- 9) Pashler, H. E. and Shiu, L-P. (1992) Improvement in line orientation discrimination. *Perception and Psychophysics* In Press.

**Papers in Preparation and Submitted for Publication**

- 10) Baylis, G. C. ,McLeod, P.M. (In Prep) Independence of errors and error correction: Evidence for independent accumulators.
- 11) Baylis, G. C. ,Mueller, P. and Pashler, H. E. (1993) Responses of neurons in inferotemporal cortex to patterns defined by texture elements.
- 12) Baylis, G. C. , Moore, B.O. and Pashler, H. E. (1993a) Hippocampal lesions impair spatial response selection in the macaque.
- 13) Baylis, G. C. , Moore, B.O. and Pashler, H. E. (1993b) Hippocampal lesions cause forgetting of skills in the macaque.
- 14) Cave, K. and Pashler, H.E. (In Prep) Rapid sequential visual presentation task and the spatial spotlight metaphor.
- 15) Pashler, H. E. and Witte, E. (1992) Combining features to recognize objects.

**Published Abstracts**

- 1) Baylis, G. C. and Driver, J. (1990) Perceptual grouping constrains visual interference. *Investigative Ophthalmology and Visual Science* 30, S
- 2) Baylis, G. C. and Driver, J. (1990) Parsing of the visual world affects perceptual judgements. *Psychonomic Society Meeting*, New Orleans, LA.
- 3) Moore, B.O., P. Alvarez-Royo, I.Y. Polis, H. Pashler and G.C. Baylis. (1989) Effects of hippocampal lesions on macaques performance of a task requiring isomorphic spatial mappings. *Society for Neuroscience Abstracts* 16, 490.10.
- 4) Mueller, P.M. , B.O.Moore, P.Alvarez-Royo, H.Pashler and G.C.Baylis (1989) The responses of neurons in the inferior temporal cortex of the macaque to patterns defined by texture elements. *Society for Neuroscience Abstracts* 16, 52.17.
- 5) Mueller, P.M., Tipper, S.P. and Baylis, G.C. (1991) The effect of normal aging and Alzheimer's Disease on spatial attention. *Society for Neuroscience Abstracts* 18, in press.
- 6) Taffe, M., Moore, B.O., Tipper, S.P. and Baylis, G.C. (1991) Action-based spatial attention in normal and hippocampal lesioned monkeys. *Society for Neuroscience Abstracts* 18, in press.